In-Delta Storage Project
Rationale for Embankment Design as Small Dams

Introduction

The cost of implementing an In-Delta storage project will depend in a large part on the design standards selected for the embankments surrounding the storage islands. More conservative design standards will reduce the risk of levee failure and annual maintenance costs, but could significantly increase construction costs. Preliminary design work by engineering staff of the Department of Water Resources (DWR) and the United States Bureau of Reclamation (Reclamation) resulted in a preliminary recommendation that the embankments for the Delta storage islands should be stronger than typical Delta levees, due to the water loading that would occur on both sides of the embankments. However, DWR and Reclamation also recommend that a risk analysis be completed as an essential component of future work, to help determine final embankment design criteria for an In-Delta storage project that would be owned by State or federal agencies.

General

The design criteria for levees and small dams is governed by the length of time these structures are continuously subjected to water loading, the extent of water loading, and the planned use of the structures.

The United States Army Corps of Engineers (USACE) defines a **levee** as an embankment, the primary purpose of which is to provide flood protection from seasonal high waters, and which is therefore subject to high water loading for periods of only a few days or weeks per year. An **earth dam** is an embankment that is used for flood control as well as water retention (and other locally relevant purposes), and is thus subject to prolonged periods of (and sometimes, permanent) significant water loading.

Even though levees may visually look like small earth dams, they differ from earth dams in the following respects:

- A levee may become saturated for only a short period of time beyond the limit of capillary saturation.
- The alignment of a levee is dictated primarily by flood protection requirements, which often results in construction on poor foundations.
- Borrow for constructing a levee is generally obtained from shallow pits or dredge spoils from channels excavated adjacent to the levee, producing fill material that is often heterogeneous and far from ideal.
- Selection of a levee section is based on the properties of the material available in the local levee area

Due to the fact that it normally experiences high water loading (i.e., flood flows) for relatively short periods of time, a levee is considered to represent a less-adverse condition than an earth dam and is typically designed for a lower safety factor (against failure) than an earth dam.

The existing embankments along the perimeter of the In-Delta project islands fit the above characteristics in general terms and are thus levees. Their function is to minimize intrusion of floodwater on to the islands from the adjacent channels. A feature that makes these levees somewhat unique is that they are subject to some level of water loading on the channel side at all times, the extent of which varies based on fluctuations in the channel water level as a result of factors like flood flows, tidal cycles, low instream flows etc. These levees have, however, never been utilized to retain water on the island-side. Moreover, the water load from the channel side is at its peak only through a fraction of the year (i.e., the flood season).

Existing Design Standards for Delta Levees

The Delta levees fall under the jurisdiction of one of the three following agencies: United States Army Corps of Engineers (USACE), Reclamation and DWR. The Delta islands contain 'project' levees and 'nonproject' levees. Project levees are those that were constructed by USACE as part of the Sacramento Flood Control Project authorized by the federal government in 1917. All other levees are nonproject levees, i.e.; they are not part of federal flood control projects. The responsibility for improvement and maintenance of project levees lies with USACE, while nonproject levees are maintained by the local Reclamation districts in accordance with DWR's standards, under the Delta Levee Subvention Program.

Depending upon the agency having jurisdiction, the delta levees have been designed based on the criteria presented in Table 1.

Water Loading on Existing Levees and Proposed Embankments for In-Delta Reservoir Islands

Figure 1 illustrates the water loading currently experienced by the existing perimeter levees on the in-Delta project islands and the expected water loading on the proposed embankments after these islands are converted to reservoirs.

The main purpose of the In-Delta storage project is water storage. The proposed embankments at the reservoir islands will therefore be subject to water loading on both sides. On the channel side, the loading will be similar to that experienced currently by the existing levees. The water surface on the island side will be as high as El +4 above mean sea level. A much higher volume of the embankment soil materials (as compared to the existing levees) will therefore remain perennially saturated. As shown in Figure 1, a comparison of the extent of seepage as it exists at present with a typical Delta levee section and the proposed embankment section with water on both sides, indicates a much larger area of saturation for the latter. For the proposed embankments, a critical stability situation will occur during low tide when the water level is at or close to the minimum on the channel side, and at its maximum (i.e., +4 MSL) on the island side.

Due to increased embankment saturation, the force impending to move the embankment towards the channel (i.e., the driving force) will be much higher than that in the case of the existing levees. This represents a stability condition that is more adverse than has ever been experienced by the existing levees.

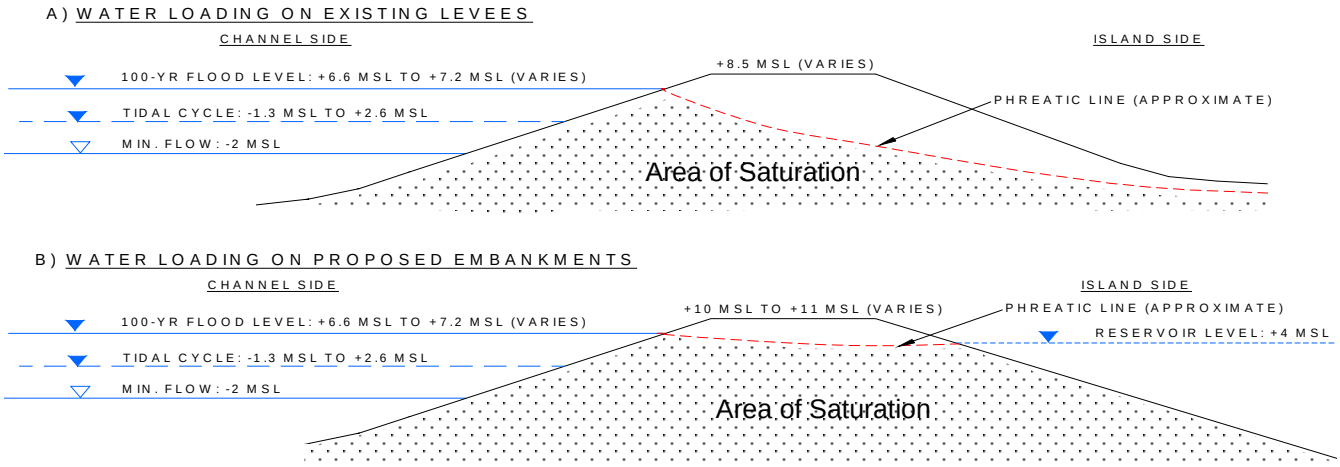
Table 1
Existing Delta Levees Design Criteria

Case	**Material Property**	**Phreatic Surface**	**Minimum Factor of Safety**		
			USACE levee	**DWR**	**Reclamation**
End of Construction	Unconsolidated undrained shear strength	Construction-induced excess pore pressures with high and low channel elevations	1.3	1.3	1.3
Sudden Drawdown	Consolidated undrained shear strength	Rapid drawdown from normal pool to dead storage with low channel elevation	1.0	1.25	1.3
Steady-state Seepage	Consolidated drained strength	Steady-state seepage under normal pool with low channel elevation	1.4*	1.3**	1.5
Post-liquefaction Stability	Based on Standard Penetration Test blowcounts	Steady-state	1.0	1.0	1.2

* Nonproject Delta Levees per PL84-99, factor of safety is 1.25
** California DWR Delta Levees

Figure 1: Water Loading on Existing Levees and Proposed Embankments, In-Delta Reservoir Islands

Note: Not to Scale



Classification of Structures and discussion of Delta Wetlands and DWR/Reclamation Recommendations for Proposed Embankments

Based on the State of California Water Code Sections 6002-6008, structures that are 25 feet or more in height, or have an impounding capacity of 50 acre-feet or more fall under the jurisdiction of the Division of Safety of Dams (DSOD), except structures not in excess of 6 feet in height regardless of storage capacity, or structures with a storage capacity less than 15 acre-feet. A dam that falls within DSOD jurisdiction is classified as a 'small dam' if its height does not exceed 50 feet.

Section 6004c of the Water Code states that "the levee of an island adjacent to tidal waters in the Sacramento-San Joaquin Delta, as defined in Section 12220, even when used to impound water, shall not be considered a dam and the impoundment shall not be considered a reservoir if the maximum possible storage elevation of the impounded water does not exceed four feet above mean sea level, as established by the United States Geological Survey 1929 datum."

The embankments proposed at the In-Delta project islands have sections with heights in excess of 25 feet. Since the maximum proposed water storage elevation is 4 feet above mean sea level, these embankments meet the exclusion stated in Section 6004c, and thus do not fall under DSOD jurisdiction. However, these embankments will be subject to water loading on both sides and high volumes of the embankment materials may be perennially saturated. This represents a stability condition that is more adverse than that experienced by the existing levees, and the

consequences of failure of these embankments could also be higher than the consequences of failure of the existing levees

It is therefore pertinent to design these embankments to standards higher than those generally utilized to design the Delta levees. In their EIR, Delta Wetlands proposed improving the existing levees in accordance with the criteria outlined in DWR Bulletin 192-82, which provides recommendations for design and construction of levees, but not for structures used for water storage.

Table 2 illustrates the embankment work proposed by Delta Wetlands and the DWR/Reclamation recommended design. Information on the existing project levees at the In-Delta islands is also included, as is the DSOD factor of safety criterion for large dams (i.e., dams having height in excess of 50 feet).

Table 2
Comparison of Embankment Design Standards

Existing Project/Nonproject Levees at In-Delta Islands	**Embankment Work proposed by Delta Wetlands**	**DWR/Reclamation Recommendations, Reengineered Project (Small Dams)**	**DSOD Dam Criterion (Large Dams)**
Existing slopes vary from 1:1 to 4:1. Crest widths vary from 12 feet to 35 feet. Sections of the levee slopes may be unsafe (i.e., may have inadequate factor of safety against failure). USACE project levees are supposed to have a minimum factor of safety of 1.4, while the minimum factor of safety for nonproject levees is 1.25, as per PL 84-99.	Existing channel-side slopes will be maintained. Additional fill will be placed on the island side to obtain a wider crest and a flatter island-side slope, to ensure that even if a part of the embankment was to fail, the remaining section would be sufficient to provide some time for repair of the failed part. URS' analysis indicated that the factor of safety for the DW-proposed embankment sections varied from 1.1 to 1.3.	Existing slopes on the channel-side to be modified to a minimum of 3:1. For a higher factor of safety against slope failure, depending upon acceptable risk and level of protection, the channel-side slopes may be modified to 4:1. Factor of safety may vary from 1.4 for a 3:1 slope to 1.5 for a 4:1 slope.	Minimum required factor of safety against slope failure is 1.5

As mentioned previously, a critical stability situation for the perimeter embankments will occur when the water level is at or close to the minimum on the channel side, and at its maximum, i.e., at +4 MSL, on the island side. Stability analysis indicates that the embankment sections proposed by Delta Wetlands will have channel-side slopes steady-state factors of safety varying from 1.1 to 1.3. Overall, the Delta Wetlands-proposed embankment sections will meet the 1.25 factor of safety criteria for nonproject levees in accordance with PL 84-99.